

Common Source/Multiple Load vs. Separate Source/Individual Load Photovoltaic System

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LOAD VS. SEPARATE SOURCE-INDIVIDUAL LOAD
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COMMON SOURCE/MULTIPLE LOAD VS SEPARATE SOURCE/INDIVIDUAL LOAD PHOTOVOLTAIC SYSTEM

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Summary

A comparison of system performance is made for two possible system setups: (1) individual loads powered by separate solar cell sources, (2) multiple loads powered by a common solar cell source. A proof for resistive loads is given that shows the advantage of a common source over a separate source photovoltaic system for a large range of loads. For identical loads, both systems perform the same.

1. INTRODUCTION

In designing a multiple load photovoltaic (PV) system, the designer may wish to compare the performance of two possible setups: a common PV array powering all loads, or separate PV arrays powering individual loads [1]. A criterion for comparing the load performance may be the "energy utilization" defined by

$$\eta^e = \int_T P(T) dT / \int_T P_m(T) dT \quad (1)$$

where the numerator is the input energy to the loads by the PV array, and the denominator is the maximum available energy that the PV array can supply; P is the PV array output power, and P_m is its maximum output power; both are functions of the solar insolation, T is time.

In a common source system there is an interaction between the loads such that it is possible that the operation of one load may be improved at the expense of another load; or the total performance of all the loads powered by a common source may also be improved. In a common source system, there exists an additional option where in certain cases, such as at low insolation, it might be advantageous to disconnect a load from the system in order to improve the operation of another load. A proof is given in the next section, for resistive loads, that shows the advantage of a common source system over a wide range of load resistance.

2. COMPARISON OF SYSTEM PERFORMANCES WITH COMMON AND SEPARATE SOLAR CELL SOURCES

The I-V characteristics of a solar cell array is shown in Fig. 1. Broadly speaking, the I-V characteristics may be divided into two ranges; range I where the solar cell behaves more likely as a current source, and range II where the solar cell behaves more likely as a voltage source.

The approximate I-V characteristics equation of the solar cell array source, neglecting the shunt resistance, is given by:

*This work was done while the author was a National Research Council - NASA Research Associate; on sabbatical leave from Tel Aviv University.

$$I = I_{ph} - I_O \left\{ \exp \left[\Lambda (V + IR_S) \right] - 1 \right\} \quad (2)$$

where I_{ph} is the photocurrent, I_O is the reverse saturation current, R_S is the series resistance, $\Lambda = q/AKT$, and $V = IR$ for resistive loads. The source terminal current and voltage are I and V , respectively.

The I-V equation of N_p such sources connected in parallel and N_s such sources connected in series, which form a larger array, is given by:

$$I_c = N_p I_{ph} - N_p I_O \left\{ \exp \left[\frac{\Lambda}{N_s} V_c + I_c \frac{N_s}{N_p} R_s \right] - 1 \right\} \quad (3)$$

where I_c and V_c are the larger array (or common) terminal current and voltage, respectively. A resistive load of value R_c , which is connected to a common solar cell array is seen by an individual source in the common array with a resistance value of:

$$R = R_c N_p / N_s \quad (4)$$

For the case where $N_p = N_s = 1$, we have $I_c = I$, $V_c = V$, $R_c = R$ and Eq. (2) applies.

Resistive loads R_1 and R_2 connected to identical separate solar cell array sources are shown in Fig. 2. The load currents are, respectively:

$$I_1 = I_{ph} - I_O \left\{ \exp \left[\Lambda I_1 (R_1 + R_s) \right] - 1 \right\} \quad (5)$$

$$I_2 = I_{ph} - I_O \left\{ \exp \left[\Lambda I_2 (R_2 + R_s) \right] - 1 \right\} \quad (6)$$

Now let these two loads be connected in parallel to a common solar cell array source ($N_s = 1$, $N_p = 2$) formed by two identical solar cell sources, as shown in Fig. 3. The equivalent load resistance is $R_c = R_1 R_2 / (R_1 + R_2)$ and the common load current I_c is:

$$I_c = 2I_{ph} - 2I_O \left\{ \exp \left[\Lambda I_c (R_c + R_s/2) \right] - 1 \right\} \quad (7)$$

For a particular case of identical loads where $R_1 = R_2 = R$, the load current of a separate source system is:

$$I = I_{ph} - I_O \left\{ \exp \left[\Lambda I (R + R_s) \right] - 1 \right\} \quad (8)$$

and the load power is:

$$P = I^2 R \quad (9)$$

The total power of two such systems is:

$$P_S = 2P = 2I^2R \quad (10)$$

where "s" stands for separate.

Now, for the common source system we have:

$$I_C = 2I = 2I_{ph} - 2I_O \left\{ \exp \left[\Lambda 2I (R/2 + R_S/2) \right] - 1 \right\}$$

or

$$I_C = 2 \left\{ I_{ph} - I_O \left\{ \exp \left[\Lambda I (R + R_S) \right] - 1 \right\} \right\} \quad (11)$$

and

$$P_C = I_C^2 R_C = 2I^2R = 2P \quad (12)$$

comparing with Eq. (10) we get:

$$P_S = P_C \quad (13)$$

The result shows that for identical resistive loads, the load powers are the same for both the separate and common source systems. (Following the same procedure one can show that this result is valid for any number of identical loads connected to a common source of appropriate size.)

The "energy utilization" is defined in eq. (1). For a given array size and insolation profile the $\int P_m dT = \text{constant}$ independently whether the cells are utilized or not. The energy utilization of the two separate source system (Eq. (10)) is:

$$\eta_S^e = \int P_S dT / 2 \int P_m dT = \int P dT / \int P_m dT \quad (14)$$

and the energy utilization of the common source system (Eq. (12)) is:

$$\eta_C^e = \int P_C dT / 2 \int P_m dT = \int P dT / \int P_m dT \quad (15)$$

where P_m is the peak power of an individual solar cell array source.

The results show that identical resistive loads which are connected to separate solar cell sources perform the same as if they are connected in parallel to a common solar cell source of the appropriate size.

We shall now analyze the performance of nonidentical resistive loads, for example, R_m and R_1 in range I and R_m and R_2 in range II, where R_m is the load resistance corresponding to the maximum power point P_m of the solar cell array source, Fig. 1. We examine first an extreme case in range I

(current source range) for $R_1 = 0$ and R_m . For the separate source system

we have $P_1 = 0$, $P_m = I_m^2 R_m$ and $P_s = P_1 + P_m = P_m$, therefore, the energy utilization of both separate systems is:

$$\eta_s^e = \int P_s dT / 2 \int P_m dT = 50 \text{ percent} \quad (16)$$

For the common source system, $P_c = 0$ since R_1 short circuits R_m , i.e.,

$\eta_c^e = 0$, therefore $\eta_s^e > \eta_c^e$.

Another extreme case is in range II (voltage source range) for $R_2 = \infty$ and

R_m . For the separate source system we have $P_m = I_m^2 R_m$ and $P_2 = 0$, therefore:

$$\eta_s^e = \int P_s dT / 2 \int P_m dT = 50 \text{ percent} \quad (17)$$

and for the common source system, $P_2 = 0$ and R_m is now powered by a double size source, therefore $P_c > P_m$ and,

$$\eta_c^e = \int P_c dT / 2 \int P_m dT > \eta_s^e \quad (18)$$

It can be shown that not only for $R_2 = \infty$ is the $\eta_c^e > \eta_s^e$, but also for large R_2 . We have mentioned three distinct cases:

(1) $R_1 = R_2 = R_m$ (identical loads whether optimal or nonoptimal), where both the separate and the common solar cell source systems have the same energy utilization;

(2) $R_1 = 0$ and R_m , where the separate source systems have a higher energy utilization than the common source system; and

(3) For R_m and large R_2 , where the common source system has a higher energy utilization than the separate source systems.

These three cases are shown in Fig. 4 by the cross marks. The solid line describes the energy utilization of the common source system η_c^e , and the dashed line the separate source systems η_s^e . Two possible trajectories (connecting the cross marks) of η_s^e are shown in Fig. 4 in range I. In one case, the energy utilization of separate source systems is always higher than the common source system; in the second case, up to point "a" the separate source systems have a higher energy utilization, but between points "a" and "b" the common source system has a higher energy utilization. In range II, the common source system is always superior ($\eta_c^e > \eta_s^e$).

An actual comparison of performances of a common source/multiple load versus separate source/individual load photovoltaic systems is shown in Fig. 5. The individual solar cell array is 1400 Wp, 176 V open-circuit voltage and 13.613 A short-circuit current. The optimal resistive load for this array is 13.5 Ω calculated by Eq. (1). For both types of systems, the optimal load was kept constant and the second load was varied between 0 and 30 Ω . The energy utilizations η_c^e and η_s^e were calculated (Eq. (1)), and plotted in Fig. 5. The figure clearly shows that for a wide range of load resistances (greater than 4.85 Ω , and including the vicinity of the optimal load for a good system design) the common source system is superior.

3. CONCLUSIONS

In designing a multiple load photovoltaic system, the designer may wish to compare the performances of separate and common solar cell array source systems. A mathematical proof is given in this paper that shows the advantage of a common source system for a wide range of load resistances. Other load types than resistive loads may exhibit similar behavior. Identical loads, either optimal or nonoptimal, of any type perform the same when powered either by separate sources or by a common source.

4. REFERENCE

[1] J. Appelbaum, "The Operation of Loads Powered by Separate Sources or by a Common Source of Solar Cells," 1989 Power Engineering Society Winter Meeting, Paper No. 89 WM 002-7 EC, N.Y.

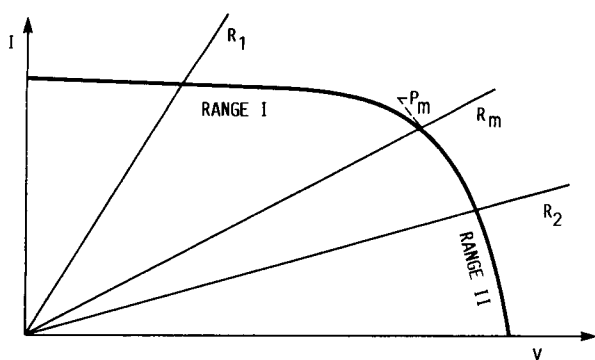


FIGURE 1. - SOLAR CELL ARRAY AND RESISTIVE LOAD I-V CHARACTERISTICS.

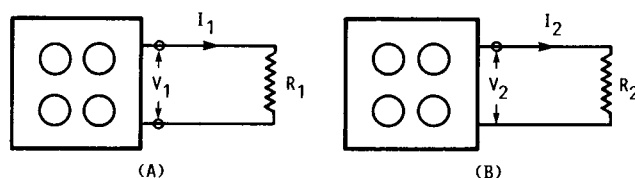


FIGURE 2. - RESISTIVE LOADS R_1 AND R_2 CONNECTED TO IDENTICAL SOLAR CELL SOURCES.

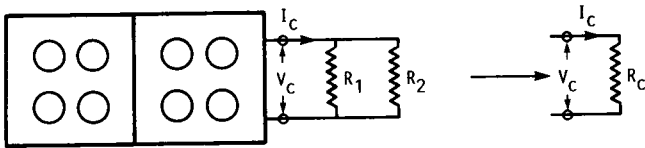


FIGURE 3. - COMMON SOLAR CELL SOURCE SYSTEM.

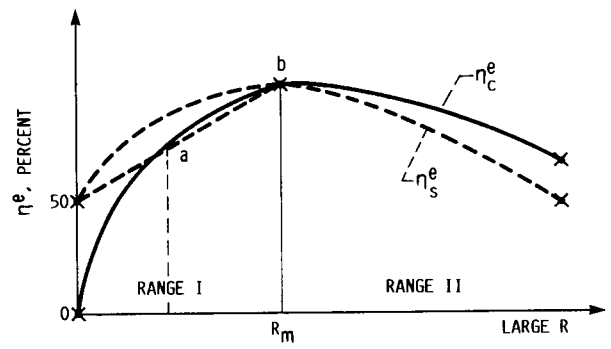


FIGURE 4. - ENERGY UTILIZATION OF SEPARATE AND COMMON SOURCE SYSTEM IN THREE EXTREME CASES $R_1 = R_2 = R_m$; $R_1 = 0$ AND R_m ; R_m AND LARGE R_2 .

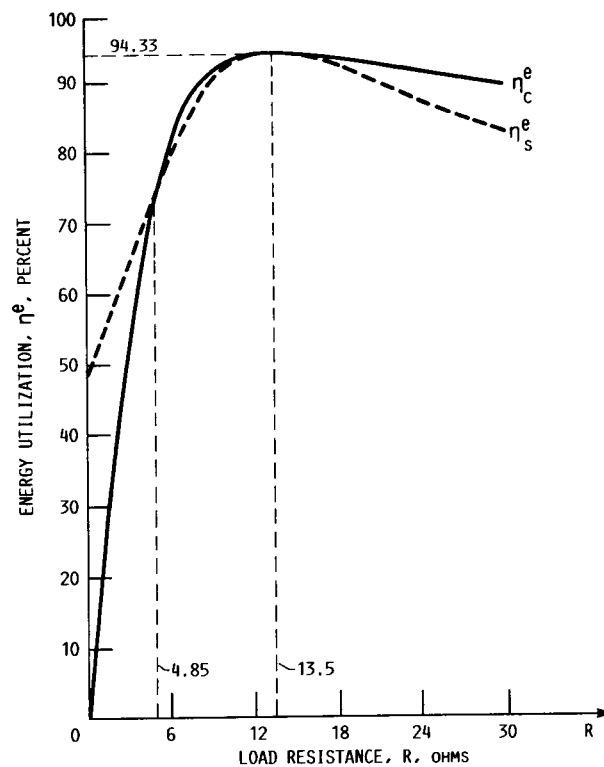


FIGURE 5. - ENERGY UTILIZATION OF SEPARATE AND COMMON SOURCE SYSTEMS FOR RESISTIVE LOADS.

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